Army Research Laboratory

Experimental Evaluation of Computer-Aided Tele-operation (CATO) and Computer-Aided Robotic Manipulation (CARMAN) Technology

by Regina A. Pomranky, Keryl Cosenzo, Andrew Bodenhamer, and Brad Pettijohn

ARL-TR-5257 **August 2010**

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14. ABSTRACT
The objective of this research was to experimentally evaluate the effect of Computer-Aided Robotic Manipulation (CARMAN) and Computer Aided Tele-operation (CATO) technologies on manipulator activity and tele-operation, respectively. These technologies were assessed to gauge their effectiveness relative to standard operation of a TALON IIIB. The CARMAN experiment consisted of a light board task with targets. CARMAN has two technologies that were evaluated in this experiment for manipulator control; Point and Click and Fly-To. These technologies were compared to the baseline configuration (ALTON). The Point and Click mode allows the operator to select a point on the video from the Operator Control Unit (OCU), which will direct the manipulator arm to move to that general area. The Fly-To mode allows the operator precise control over the manipulator arm, via a joystick on the OCU, to direct the end effector to a specific point. Results showed that performance with the Fly-To configuration was superior to the other two configurations. The CATO Experiment consisted of a path-following course and an obstacle negotiation course. CATO has three technologies that were evaluated in this experiment for tele-operation, Elevated Camera, Projected Path, and Waypoint. These technologies were compared to the baseline configuration (TALON). Elevated Camera was best suited for completing the obstacle course both in terms of speed and minimizing collisions. Projected Path was found to be best for following a designated path and was also well suited for avoiding collisions with obstacles. Both Elevated Camera and Projected Path were found to significantly reduce the reported frustration of operating the SUGV for these tasks.

15. SUBJECT TERMS
TALON, ALTON, CATO, CARMAN, aided tele-operation

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1. Introduction

The objective of this research was to experimentally evaluate the effect of Computer-Aided Robotic Manipulation (CARMAN) and Computer Aided Tele-operation (CATO) technologies on manipulator activity and tele-operation, respectively. These technologies were assessed to gauge their effectiveness relative to standard operation of a TALON* IIIB. A secondary objective was to develop a set of metrics that will test the tele-operated robotic manipulation and mobility of the CARMAN and CATO technologies and may have applications to other robotic technologies.

1.1 Background

The Battlefield Automation Team (BAT) of the Aviation and Missile Research, Development and Engineering Center (AMRDEC) Software Engineering Directorate (SED) has two projects entitled CARMAN and CATO. CARMAN involves the development of technologies to reduce robotic manipulator task times and improve the precision of robotic manipulator placement. CATO involves the development of technologies to reduce tele-operated robotic mobility task times and improve the precision of tele-operated driving. The first goal for this experiment was to operationally and technically measure CARMAN and CATO technology performance.

The unmanned systems community did not have a set of accepted metrics that measured robotic performance for these tasks, particularly the manipulator placement task. Currently, measures of effectiveness for robotic systems include parameters such as weight, size, packability, usability, mean time between failures (MTBF) and mean time to repair (MTTR). Although these measures need to be collected and validated to ensure effectiveness of the system, they do not measure operational performance. A second goal for this study was to develop a set of robotic metrics that are suitable for tele-operated robotic manipulation and mobility, and then to use these metrics to evaluate the performance of both CARMAN and CATO.

1.2 CARMAN

Tele-operated unmanned ground vehicle (UGV) manipulators currently deployed in support of contingency operations provide limited sensory data to the operator. Visual data relayed to the operator fails to provide accurate depth perception and an adequate field of view while tactile and auditory data are typically nonexistent. The resulting shortfall in situational awareness fundamentally limits manipulator system effectiveness in terms of spatial precision and the time required to perform manipulation tasks. Compounding these limitations is an inadequate match between machine characteristics and operator capabilities. The Operator Control Units (OCU) supplied with current manipulator systems either burden the operator with low-level tasks, such

* TALON is a registered trademark of Foster-Miller, Inc. – QinetiQ North America, Waltham, MA.

as individually controlling manipulator joints, or presents an overwhelming set of operating. modes designed for a multitude of manipulation tasks. In either case, current manipulation systems consume an undue amount of an operator's attention, detracting from mission focus. This in turn unnecessarily lengthens task completion and operator exposure time in hostile environments and increases the number of assets needed to support a given workload.

CARMAN has two technologies that were evaluated in this experiment for manipulator control; Point and Click and Fly-To. The Point and Click mode allows the operator to select a point on the video from the OCU that will direct the manipulator arm to move to that general area. The Fly-To mode allows the operator precise control over the manipulator arm via a joystick on the OCU, to direct the end effector to a specific point. These modes are in contrast to the current manipulator implementation strategy, where the operator actively moves the arm to the location via joystick control manipulating each joint movement independently.

1.3 CATO

Soldiers tele-operate small UGVs in the current force by looking at a video display or line of sight of the robot and moving a joystick. CATO was developed to bridge the gap between current and future UGVs where there will be increased autonomy. There are four technologies for CATO; some are only software, some only hardware, and some a combination of both. The technologies that were developed were collaborative unmanned aerial vehicle (UAV) driving camera, projected path display driving, short distance operator selected waypoint driving, and elevated rear mounted driving camera.

1.3.1 Collaborative UAV Driving Camera

The collaborative UAV driving camera is teamed with a UAV and the ground vehicle. The UAV camera will give an overhead visual perspective to the operator in conjunction with the regular UGV driving camera(s). This view is also intended to increase the view of the area surrounding the UGV, increasing the operator's situational awareness. The UAV is positioned collaboratively above and slightly behind the UGV. It is commanded by the operator to position itself based on the location and heading of the UGV. This eliminates the need for the operator to command the UAV. The notion is that the UAV driving camera would be added as an additional camera selection of the UGV so the operator can select it or any of the other UGV cameras as necessary to display current video. Due to technical challenges with the UAV driving camera configuration, this CATO technology was not included in this experiment.

1.3.2 Projected Path Display Driving

The projected path display driving uses the normal UGV driving camera to project a virtual path on the operator control display. The semi-transparent path is projected in front of the actual UGV. The projected path indicates where the UGV will travel if the control input remains constant. This technology was largely a software solution.

1.3.3 Operator-Selected Waypoint Driving

The short distance operator-selected waypoint driving provides the operator the ability to visually identify and then select waypoints on the OCU display using existing UGV cameras. The operator views the display and identifies desired waypoints using an input device. The UGV follows the waypoints at a selected speed and automatically stops at the last specified waypoint. Waypoint following allows the vehicle to move forward in the battle without continuous operator interaction with the robot. As a result the operator can move his position or fight while using a robot.

1.3.4 Elevated Rear-Mounted Driving Camera

The elevated rear-mounted driving camera is a modification in which the driving camera is behind and above the UGV. This perspective gives a third person view of the UGV and increases the view of the surrounding area. This is primarily a hardware solution and required minimal modification to existing systems.

The three available CATO technologies were assessed to gauge their effectiveness relative to standard tele-operation of a small unmanned ground vehicle (SUGV). CARMAN and CATO were implemented on the TALON IIIB platform and OCU.

This report documents two independent experiments. The first experiment tested the CARMAN technology and was conducted using a light board and the ALTON (a modified TALON IIIB) platform with and without Point and Click and Fly-To technologies. The second experiment was conducted on an obstacle course that was run using the TALON IIIB platform, with and without the CATO Projected Path Display Driving, Operator Selected Waypoint Driving, and Elevated Rear Driving Camera technologies.

2. Method

2.1 Participants

Participants were 12 civilian men and women ranging in age from 18 to 25 years old, recruited from the AMRDEC workforce. Participants had roughly the same level of experience with operation of unmanned systems, which was determined from recruiting techniques and verified by the demographics questionnaire. Participants completed an Informed Consent form (appendix A) and a Demographics Questionnaire (appendix B) prior to the beginning the experiment.

2.2 Apparatus

2.2.1 Hardware

2.2.1.1 The TALON IIIB

The TALON IIIB (figure 1) is a tracked UGV that is widely used for explosive ordnance disposal (EOD), reconnaissance, communications, hazmat, security, defense and rescue applications. The TALON weighs 115 lb and has a top speed of 5.2 mph. The manipulator arm has three degrees of freedom and cannot rotate independently of the robot body. The TALON IIIB is the primary robot used for improvised explosive device (IED) interrogation by the U.S. Army Engineers.

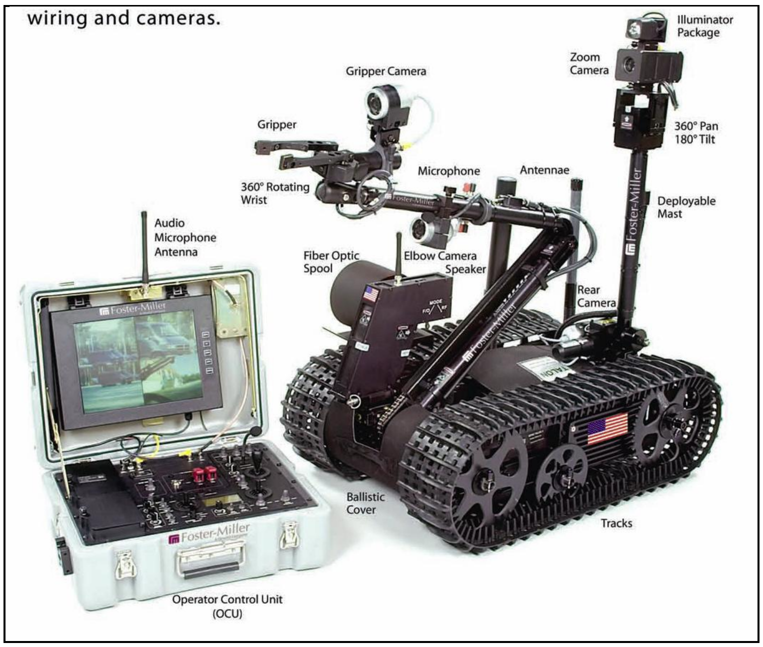

Figure 1. TALON IIIB and OCU.

2.2.1.2 ALTON

The ALTON robot is a customized version of the TALON IIIB robot that has been upgraded to improve sensor accuracy and data rates. In order to realize these improvements in performance, it was necessary to upgrade the internal electronics and software in both the robot and the operator control unit. The resulting increase in sensor accuracy and data rates allows smoother, more controlled motion of the platform and its manipulator. Although ALTON has new internal electronics, the mechanical chassis and motors are identical to those of a TALON IIIB.

2.2.1.3 OCU

The OCU, shown in figure 2, is an encased control unit with a display and joysticks that control driving, manipulator arm, and payloads (i.e., cameras). The OCU used in these experiments physically mirrors the external appearance of the Foster Miller–TALON IIIB OCU with the

exception of a second two-axis controller and an extra mode Miller–TALON IIIB OCU with the exception of a second two-axis controller and an extra mode switch button on the right hand side of the OCU face. Internally, the OCU has an onboard computer and custom electronics to accommodate the interface. The modifications to the TALON IIIB OCU did not affect how the operator interacted with the baseline TALON IIIB capabilities. The modified TALON IIIB OCU with or without the CARMAN and CATO technologies is referred to as ALTON in the remainder of this document.

Figure 2. Operator control unit.

2.2.1.4 GPS Data Logger

The data logger is a custom data acquisition system that recorded GPS position data for the UGV under test. The data logger uses a Novatel GPS receiver in RT2 mode with an accuracy of 2 cm. The data logger is self-contained and powered by its own battery. It is contained in an aluminum enclosure with dimensions (in inches) 5.125×6.25×3.125, which allows it to be mounted to the UGV with minimal impact on weight and volume.

2.2.1.5 Light Board

A 3×4 ft rear-projection light board was used for the CARMAN tasks (see figure 3). The Magic-Touch light board is a positional measurement tool designed to report the X and Y position of an object penetrating the area enclosed in the frame. The light board is able to determine the position of penetration by using an overlapping array of Infrared LEDs. Once an object breaks the beam it is recorded on a computer. Three-dimensional (3-D) perception is known to be hard for the robotic operator using the standard TALON vision system, especially for novice operators. In order to achieve “clean” results, a standard vision system was used to minimize the variable of assessing depth, hopefully to reduce the variability that would be induced by relying on the operator's ability to perceive depth from cues that are irrelevant to the technologies being analyzed. Two operationally relevant actions were assessed in the touch task: (1) Pan/Tilt of the

arm to achieve “bore-sight” alignment of the gripper with the target and, (2) Maintaining steady trajectory as the gripper approaches the target. These two steps (along with the use of shadows to assess depth) are generally how the robotic manipulator is used in real environments. Additionally the operator could push through the screen because it is paper, thus the paper can easily be repaired/replaced. By using the Magic-Touch light board the sensors registered a “hit” before the pointer touched the paper.

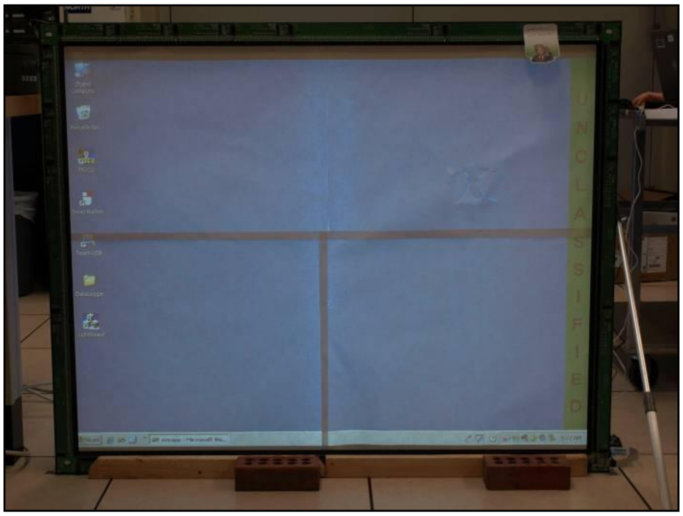

Figure 3. Light board task.

2.2.2 Screening and Demographic Measures

2.2.2.1 Demographic and Computer Experience Questionnaire

The Demographic and Computer Experience Questionnaire (appendix B) is a 12-item questionnaire that requests information regarding age, vision, hearing, and computer experience. This questionnaire was used to gain basic demographic information about the participant sample.

2.2.2.2 The NASA-Task Load Index (NASA-TLX)

Participants were given the NASA-TLX subjective workload rating at the end of each task (appendix C, Hart and Staveland, 1987).[1] The NASA-TLX is a multi-dimensional rating procedure that derives an overall workload score based on a weighted average of ratings on six subscales (Mental Demand, Physical Demand, Temporal Demand, Own Performance, Effort, and Frustration). Scores range from 0 (no workload) to 100 (extremely high workload).

2.2.2.3 Motion Symptom Questionnaire

This questionnaire provides a subjective rating on the participant’s perceived levels of motion sickness before and after the experiment (appendix D, Gianaros, Muth, Mordkoff, Levine, and

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[1]Hart, S. G.; Staveland, L. E. Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In P.A. Hancock and N. Meshkati Eds., *Human Mental Workload*. Amsterdam: Elsevier, 1987.

Stern, 2001).[2] A comparison of the pre- and post-experimental response patterns across the questionnaire was conducted to evaluate motion sickness. Any subjects showing elevated scores on any of the items was held at the research site until their symptoms abated. No motion sickness was reported during the experiments.

2.2.3 General Procedures

Prior to the start of the experiment, the experimenter briefed the participants on the purpose and procedures of the experiment. Participants who agreed to take part in the study signed the Volunteer Agreement Affidavit (appendix A) and were given the required briefing regarding confidentiality as indicated on DA Form 5303-R. In anticipation of possible concerns regarding personal answers on some of the questionnaires, the investigators also described the deliberate actions taken when handling research data. In order to ensure that individual data was not reported or revealed to anyone, each form was reviewed upon receipt by one of the investigators. If any identifying information appeared on the questionnaires (such as name, social security number, birth date, etc.), the investigators deleted the identifying information and replaced it with a neutral code number. This code number became the participant identification number used in data files.

Participants were told that they would complete two experiments in an 8 h block, over the course of one day. In experiment I, participants manipulated the ALTON manipulator arm with and without the CARMAN Point and Click and Fly-To technologies. In experiment II, the participant tele-operated the TALON IIIB through an outdoor obstacle course with and without the CATO Elevated Rear-Mounted Driving Camera Mode, Projected Path Display Driving Mode, and Operator-Selected Waypoint Driving Mode technologies. There was a 30 min break between each experiment and 45 min given for lunch. One-half of the participants completed experiment I and then experiment II. The other half completed experiment II first followed by experiment I.

2.3 Experiment I—CARMAN Procedures

After a description of the purpose, participants were given an overview of and training on the baseline configuration of the CARMAN configurations. The experimenter presented the functionality of the CARMAN OCU. The participant completed a training trial. They had the opportunity to repeat the training run again until they were comfortable controlling the robot. Criteria for efficient training were determined by a subject matter expert on the platform who was present during the training mission. These subject matter experts were the engineers of the CARMAN and CATO software and they used their knowledge of the system to assess training effectiveness. The objective of the CARMAN task was to manipulate the manipulator arm to hit 20 targets that were displayed on the rear-projection light board. The participants were

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[2] Gianaros, P. J.; Muth, E. R.; Mordkoff, J. T.; Levine, M. E.; Stern, R. M. A Questionnaire For the Assessment of the Multiple Dimensions of Motion Sickness. *Aviation Space Environmental Medicine* **2001** 72 (2), 115–9.

instructed to perform this task as quickly and accurately as possible. Figure 4 shows the manipulator pointing at a target on the light board.

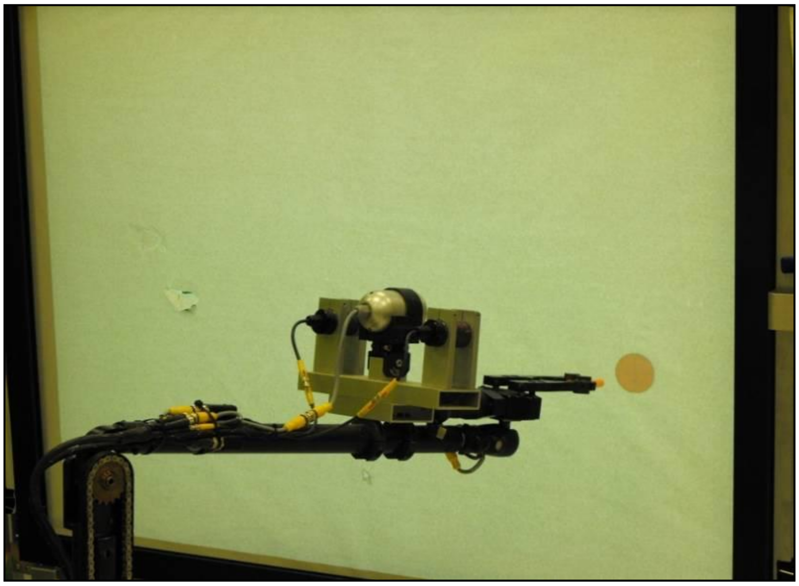


Figure 4. Manipulator pointing at a target on the light board task.

All targets were the same size bull's-eye-shaped figures that were projected in three random patterns on the light board. Each pattern contained 20 targets that were evenly distributed throughout the target board, meaning that in each pattern, special care was taken to ensure that equal numbers of quadrants were used and that the space between targets was similar. Participants completed two trials per configuration, baseline configuration (i.e., ALTON), CARMAN Point and Click, and Fly-To configuration. Participants were instructed to use the manipulator arm to touch 20 targets that appeared in succession on the light board as quickly and accurately as possible. Each target appeared and stayed lit until the participant touched the manipulator end point somewhere in the target or the time for a target hit ran out (20 s). If the manipulator arm touched some place other than inside the target, it was considered an inadvertent contact. Accuracy was measured by distance from the center of the bull's-eye. Once a hit occurred the target disappeared and the next target appeared. The participant continued until all 20 targets were hit. Each participant completed six trials using the ALTON OCU (see figure 5).

Figure 5. Participant controlling the manipulator arm through the operator control unit.

Participants completed the task with only visual sightings of the target board through the OCU. A tarp separated the participant from the TALON platform rendering the task as non-line-of-sight. Additionally, participants could not see the entire target board through the OCU. As a result, participants often had to back up the manipulator arm to get a wider view of the target board, which allowed them to identify the target area. Speed and accuracy were stressed. Subject matter experts observed the trials for technical difficulties. After each CARMAN task trial, the participants completed the NASA-TLX and were given the opportunity to take a thirty-minute break before beginning the next experiment.

2.3.1 Experiment I—Experimental Design

The experimental design of experiment I was a 3×2 within subjects design. There were two independent variables, configuration type with three levels (baseline [i.e., ALTON], Point and Click, and Fly-To) and trial with two levels (trial 1 and trial 2). Thus, the participant completed two trials in the baseline configuration, two in Point and Click, and the two in the Fly-To configuration. In all, each participant completed six trials. In each trial there were 20 targets to touch with the manipulator on the light board. Task completion time for experiment I was approximately 2 h.

Configuration Type:

- A=Baseline (ALTON)
- B=CARMAN with Point and Click
- C=CARMAN with Fly-To

Repetition:

- 1 and 2

Target Order:

- (1), (2), (3)

Order of the conditions was counterbalanced using a Williams Square Design (see table 1).

Table 1. Order of conditions for experiment I.

Participant	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
1	A1(2)	B1(3)	C1(1)	A2(3)	B2(1)	C2(2)
2	B1(1)	C1(2)	A1(3)	B2(2)	C2(3)	A2(1)
3	C1(3)	A1(1)	B1(2)	C2(1)	A2(2)	B2(3)
4	A1(1)	C1(2)	B1(3)	A2(2)	C2(3)	B2(1)
5	B1(2)	A1(3)	C1(1)	B2(3)	A2(1)	C2(2)
6	C1(3)	B1(1)	A1(2)	C2(1)	B2(2)	A2(3)
7	A1(1)	B1(2)	C1(3)	A2(2)	B2(3)	C2(1)
8	B1(2)	C1(3)	A1(1)	B2(3)	C2(1)	A2(2)
9	C1(3)	A1(1)	B1(2)	C2(1)	A2(2)	B2(3)
10	A1(1)	C1(2)	B1(3)	A2(2)	C2(3)	B2(1)
11	B1(2)	A1(3)	C1(1)	B2(3)	A2(1)	C2(2)
12	C1(3)	B1(1)	A1(2)	C2(1)	B2(2)	A2(3)

Dependent Variables:

The following dependent variables were measured by automatic data collection and survey instruments during experiment I.

Time to complete (milliseconds) (digitally recorded with embedded automatic data collection software):

- Average Time per Trial
- Average Time per Target

Precision and Errors frequency (digitally recorded with embedded automatic data collection software):

- Inadvertent Contacts
- Missed Targets (Timed out)

Subjective Responses (surveys):

- Workload was measured with the NASA-TLX.

Analyses for experiment I:

- Means and standard errors were calculated for each dependent variable.

To examine the effects of CARMAN configuration type on operator performance (e.g., time, precision), a mixed linear model analysis was conducted. Subsequent pairwise comparisons were conducted for the significant dependent variable(s). Effects showing significance of $p<0.05$ were considered statistically significant.

To examine the effects of CARMAN configuration type on workload, a MANOVA was conducted with scores on the six subscales of the NASA-TLX (Mental Demand, Physical Demand, Temporal Demand, Own Performance, Effort, and Frustration) as the dependent variables. Effects showing significance of $p \leq 0.05$ were considered statistically significant. Subsequent repeated measures ANOVAs were conducted for the significant dependent variable(s).

2.4 Experiment II—CATO Procedures

After a description of the purpose, participants were given an overview of the CATO and training on the baseline CATO configuration. The experimenter presented the functionality of the OCU for CATO. The participant completed a training trial. Criteria for efficient training were determined by a subject matter expert on the platform who was present during the training mission. These subject matter experts were the engineers of the CARMAN and CATO software and used their knowledge of the system to assess training effectiveness. After training, the participant completed the CATO tasks, the objective was to maneuver the unmanned system through the obstacle course.

The obstacle course consisted of two segments: path following and obstacle negotiation. The path following segment consisted of following a painted orange line through seven corners and curves. The obstacle segment consisted of traveling through four gates (2 widths×2 approach orientations), a ramp, a narrow passageway, a tightly-spaced five cone slalom, a gate on a curve, and a four cone slalom (a total of 16 obstacles). For each trial, the operator navigated the course in one continuous run, with individual segment times being recorded by stopwatch. Collisions with obstacles were noted by a data collector. All tele-operation was conducted "non-line-of-sight" from a nearby climate controlled shelter; this means that at no time was the participant able to directly view the robot. Participants were instructed to stress accuracy (precision path following and avoiding obstacle collisions), but to also drive as quickly as they felt they could while remaining accurate in their maneuvers. Subject matter experts observed the operators' use of the equipment during the trials for usability issues. After each CATO task trial, the participant

completed the NASA-TLX and was given the opportunity to take a 30-min break before beginning the next experiment. The driving course is shown in figures 6–8.

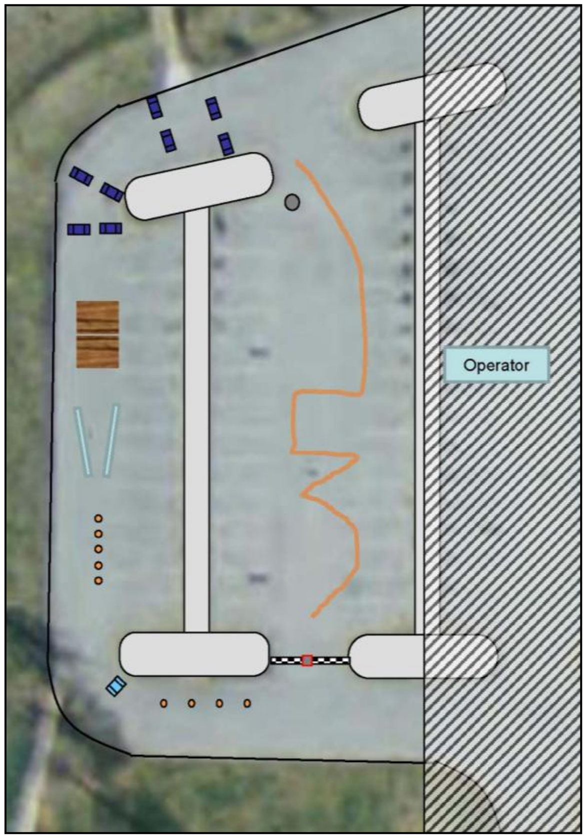


Figure 6. Sketch of CATO driving course.

Figure 7. TALON on path following course.

Figure 8. ALTON negotiating obstacles.

2.4.1 Experimental Design

The experimental design of experiment II was a 4×2 within subjects design. There were two independent variables, configuration type with four levels (baseline [i.e., TALON], Elevated Rear Mounted Driving Camera, Projected Path Display Driving, and Operator Selected Waypoint Driving) and repetition with two levels (trial 1 and trial 2). Thus, the participant completed two trials in the baseline configuration, two in the CATO Elevated Rear Mounted Driving Camera configuration, two in the CATO Projected Path Display Driving configuration, and two in the CATO Operator Selected Waypoint Driving configuration. In all, each participant completed eight trials. The obstacle course remained in a static configuration, trials alternated running the course from “start to finish” and from “finish to start” to maintain consistent course length but reduce learning effect. Task completion time for experiment II was approximately 3 h.

Configuration Type:

- A=Baseline (ALTON)
- B=CATO with Elevated Rear Mounted Driving Camera
- C=CATO with Projected Path Display Driving
- D=CATO with Operator Selected Waypoint Driving

Trial:

- 1 and 2

Order of the conditions was counterbalanced using a Williams Square Design as shown in table 2.

Table 2. Order of conditions for experiment II.

Participant	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8
1	A1	D1	B1	C1	A2	D2	B2	C2
2	B1	A1	C1	D1	B2	A2	C2	D2
3	C1	B1	D1	A1	C2	B2	D2	A2
4	D1	C1	A1	B1	D2	C2	A2	B2
5	C1	B1	D1	A1	C2	B2	D2	A2
6	D1	C1	A1	B1	D2	C2	A2	B2
7	A1	D1	B1	C1	A2	D2	B2	C2
8	B1	A1	C1	D1	B2	A2	C2	D2
9	A1	B1	C1	D1	A2	B2	C2	D2
10	B1	D1	A1	C1	B2	D2	A2	C2
11	C1	A1	D1	B1	C2	A2	D2	B2
12	D1	C1	B1	A1	D2	C2	B2	A2

Dependent Variables:

The following dependent variables were measured during experiment II.

Time in seconds (recorded by the U.S. Army Research Laboratory [ARL] data collector with stopwatch):

- Time to complete path following segment
- Time to complete obstacle segment

Precision and Errors:

- Path following precision (measured by GPS data logger)
- Number of obstacle collisions (measured by ARL data collector)

Power consumption used by the Robot (recorded by ARL data collector using in-line power consumption meter)

Subjective Responses (surveys):

- Workload was measured with the NASA-TLX.

Analyses for experiment II:

- Means and standard errors were calculated for each dependent variable.

Path following precision was evaluated by calculating the area of deviation between the path taken and the true course. The output is a deviation score in pixels determined by the program that calculates the area between the lines. This method was chosen for its simplicity and

insensitivity to path following time. To examine the effects of CATO configuration type on operator performance (e.g., time, precision), a mixed linear model analysis was conducted. Subsequent pairwise comparisons were conducted for the significant dependent variable(s). Effects showing significance of $p \leq 0.05$ was considered statistically significant.

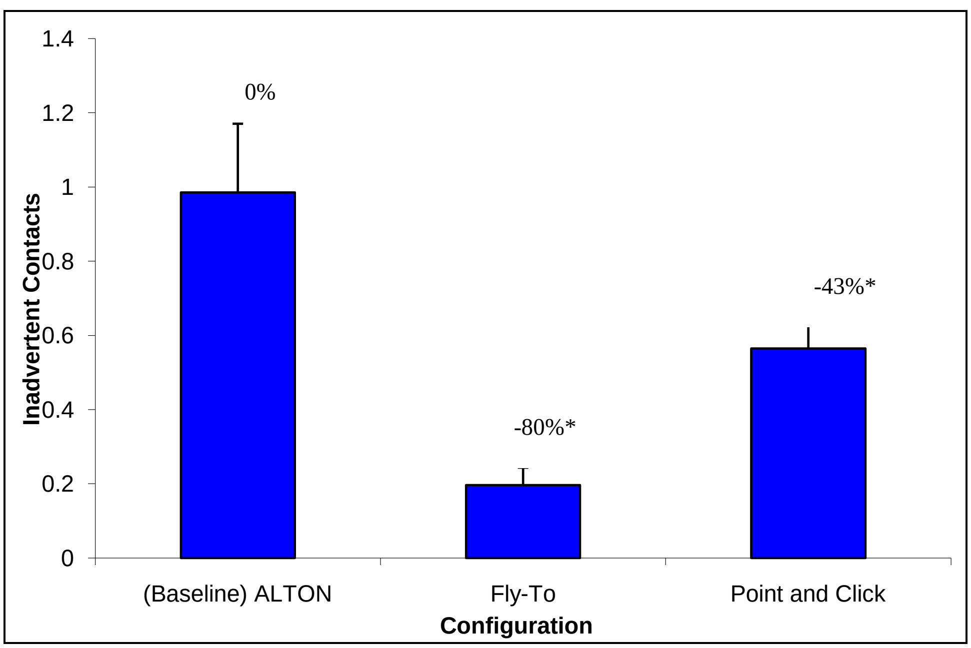
To examine the effects of CATO configuration type on workload, a MANOVA was conducted with scores on the six subscales of the NASA-TLX (Mental Demand, Physical Demand, Temporal Demand, Own Performance, Effort, and Frustration) as the dependent variables. Effects showing significance of $p \leq 0.05$ was considered statistically significant. Subsequent repeated measures ANOVAs were conducted for the significant dependent variable(s).

3. Results

3.1 CARMAN Results

To examine the effects of the three CARMAN configurations (ALTON, Point and Click, and Fly-To) and Repetition (1 and 2) on performance in the light board task, repeated measures ANOVAs and subsequent pairwise comparisons were conducted.

Figure 9 presents a graph of inadvertent contacts on the light board task. Results for the light board task showed that the number of inadvertent contacts was highest in the ALTON configuration. There was an 80% and 43% average reduction in inadvertent contacts with the Fly-To and Point and the Click configurations, respectively.

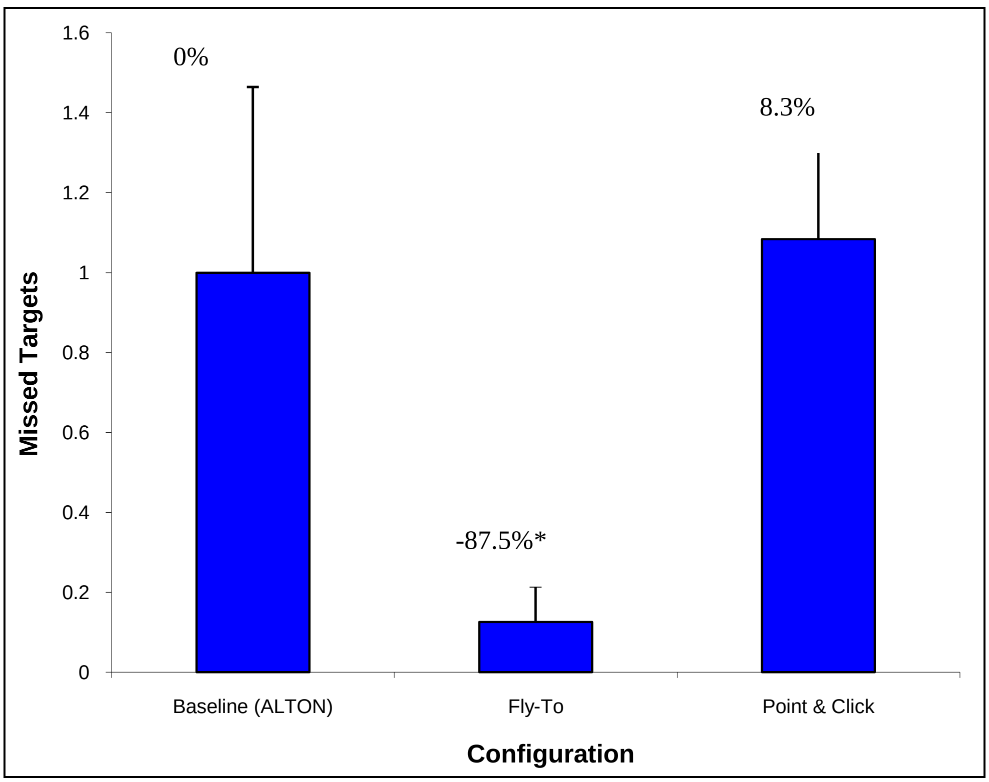


Note: * = a significant difference.

Figure 9. Graph of the percentage of inadvertent contacts for CARMAN configurations.

A repeated measures ANOVA revealed a significant main effect of CARMAN configuration for inadvertent contacts, F (2,22) = 18.01, p<0.01. There was no difference in missed targets between trial 1 and trial 2 or an interaction of trial with configuration, F (1,11) = 0.04, p<0.83 and F (2,22) = 0.44, p<0.64, respectively. To explain the main effect of configuration on missed targets, pairwise comparisons were conducted. Results showed that significantly more targets were missed in the ALTON than the Point and Click or Fly-To configurations, p<0.01 for each. Furthermore, more targets were missed in the Point and Click than the Fly-To configuration, p<0.01.

Figure 10 presents a graph of Mean (Standard Error of the Mean [error bars]) Missed Targets for CARMAN configurations on the light board task. Results for the light board task showed that the number of misses was higher in the Point and Click configuration than in the Baseline (ALTON) configuration. The number of misses in the Fly-To configuration was less than a third of the number of misses in the Baseline (ALTON) configuration.

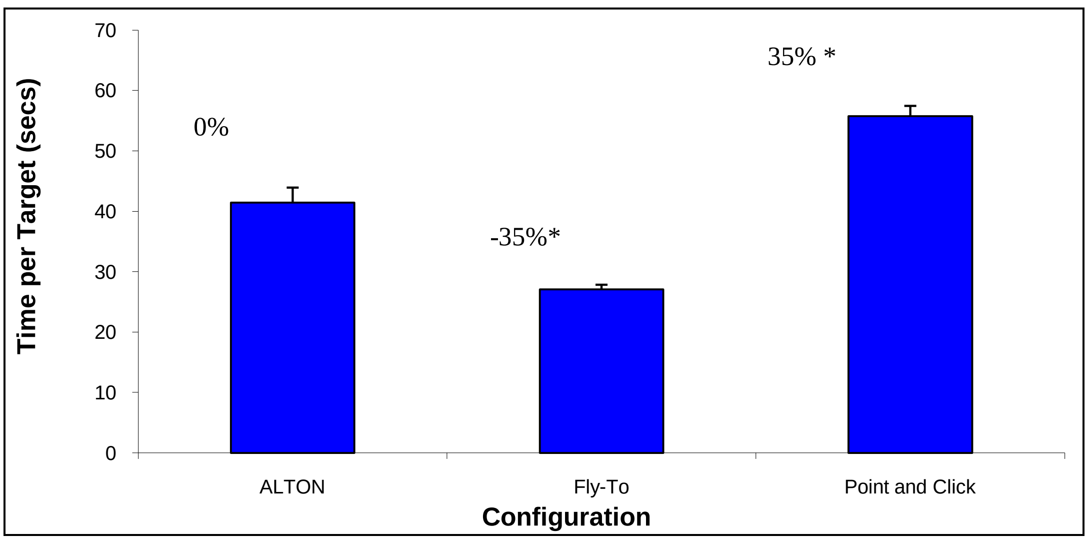


Note: * = p<0.01.

Figure 10. Graph of mean (standard error of the mean) missed targets for CARMAN configurations; percent change relative to baseline (ALTON) in missed targets is represented above each bar.

A repeated measures ANOVA revealed a significant main effect of CARMAN configuration for number of missed targets (out of twenty), F (2, 22) = 4.35, p<0.02. There was no difference in missed targets between trial 1 and trial 2 or an interaction of trial with configuration, F (1,11) = 3.98, p<0.07 and F (2,22) = 2.46, p<0.10, respectively. To explain the main effect of configuration on missed targets, pairwise comparisons were conducted. Results showed that more targets were missed in the Point and Click than the Fly-To configurations, p<0.01. No other comparisons were statistically significant. Although there was a large difference between the Fly-To configuration and Baseline, this difference was not statistically significant. It is important to note that an 87.5% reduction in missed targets is notable and has practical significance.

Figure 11 presents a graph of mean task completion time (seconds) on the light board task. Results for the light board task showed that task time was shortest in the Fly-To mode. Furthermore, task time was slightly shorter in the ALTON configuration than the Point and the Click configuration.

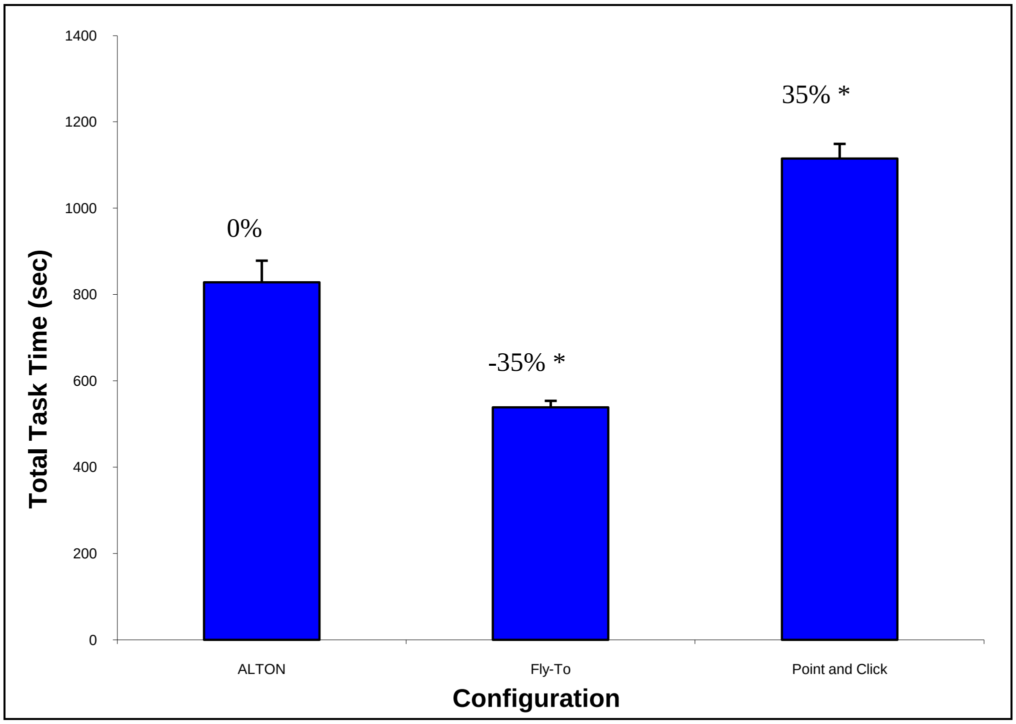


Note: * = p <0.01.

Figure 11. Graph of mean (standard error of the mean) time per target for CARMAN configurations.

A repeated measures ANOVA revealed a significant main effect of CARMAN configuration for task completion time, F (2,22) = 93.79, p<0. 01. There was no significant difference in task completion time between trial 1 and trial 2 or an interaction of trial with configuration, F (1,11) = 2.96, p<0.10 and F (2,22) = 0.448, p<0.64, respectively. To explain the main effect of configuration on task time, pairwise comparisons were conducted. Results showed that task time was significantly shorter in the Fly-To configuration than the Point and Click or the ALTON configuration, p<0.01 for each. Task time was significantly shorter in the ALTON than in the Point and Click configuration, p<0.01.

Figure 12 presents a graph of mean total time to complete the light board task. Results for the light board task showed that the Point and Click configuration took the longest to complete. The Fly-To configuration had the shortest task completion time.



Note: * = p<0.01.

Figure 12. Graph of mean (standard error of the mean) total task time (seconds) for CARMAN configurations.

A repeated measures ANOVA revealed a significant main effect of CARMAN configuration for total task time, F (2, 22) = 92.43, p<0.01. There was no difference in time between trial 1 and trial 2 or an interaction of trial with configuration, F (1,11) = 3.52, p<0.08 and F (2,22) = 0.37, p<0.69, respectively. To explain the main effect of configuration on total task time, pairwise comparisons were conducted. Results showed that task time was significantly longer in the ALTON and Point and Click configurations than the Fly-To configuration, p<0.01 for each. Furthermore, task time was significantly longer in the Point and Click than the ALTON, p<0.01.

To examine the effects of the three CARMAN configurations (ALTON, Point and Click, and Fly-To) on subjective workload, a Multivariate Analysis of Variance (MANOVA) was conducted. Subsequent ANOVAs and pairwise comparisons were conducted for the significant workload subscales.

Figure 13 presents a graph of mean workload across the CARMAN configurations. Results showed that subjective workload, specifically mental demand, physical demand, temporal demand, and frustration, were highest in the ALTON. Furthermore, workload on those subscales was lowest in the Fly-To configuration (also shown by percentages in table 3).

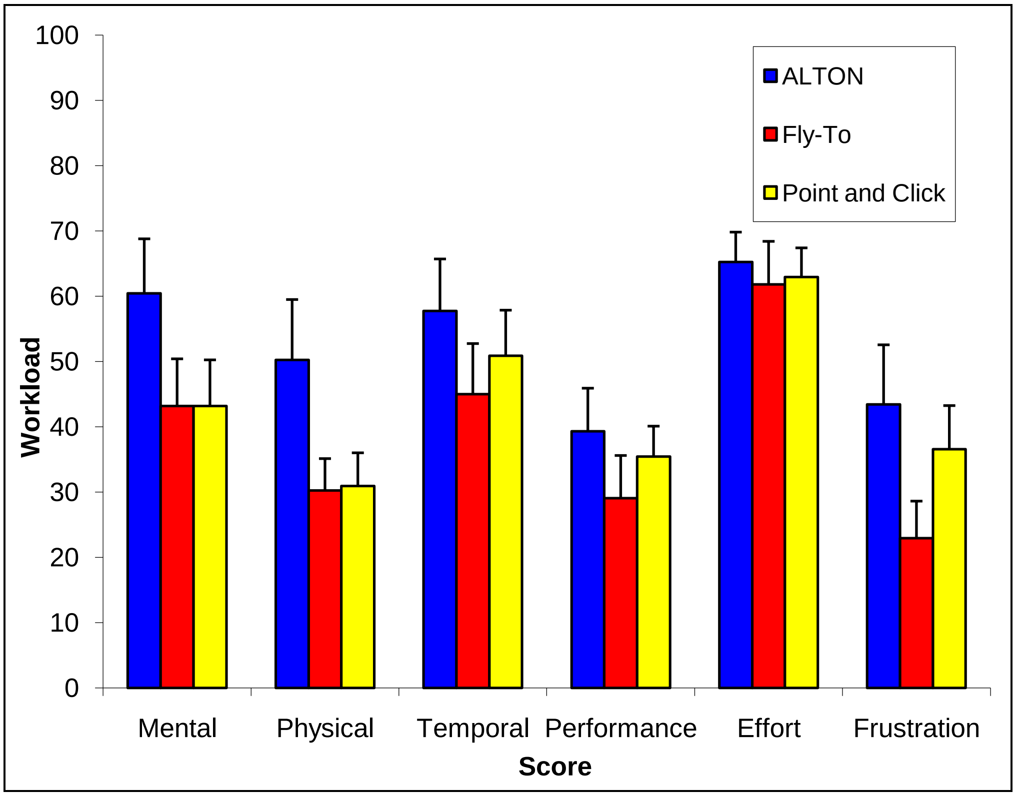


Figure 13. Graph of mean (standard error of the mean) subjective workload for CARMAN configurations.

Table 3. Table of percentages of workload from baseline (ALTON) by configuration.

	Mental	Physical	Temporal	Performance	Effort	Frustration	Overall Workload
Baseline (ALTON)	0%	0%	0%	0%	0%	0%	0%
Fly-To	–29.6%[a]	–39.8 [a]	–22.0%[a]	–26.0%	–5.2%	–47.1%[a]	–25.1%[a]
Point and Click	–29.6%[a]	–38.5%[a]	–11.8%	–9.8%	–3.5%	–15.7%[a]	–16.2%[a]

[a]Significant comparison between configuration and baseline (ALTON), $p<0.05$.

A repeated measures MANOVA revealed a significant main effect of CARMAN configuration on workload, F (12, 32) = 2.92, $p<.01$. There was no difference in workload between trial 1 and trial 2 or an interaction of trial with configuration, F (6,5) = 1.10, p = 0.46 and F (12,32) = 1.04, p = 0.43, respectively. Subsequent ANOVAs were conducted to determine which subscales of

the NASA-TLX workload scale contributed to this main effect. There were significant main effects for mental demand, physical demand, and frustration, F (2,20) = 9.65, p<0.01, F (2,20) = 7.53, p<0.01, and F (2,20) = 5.37, p<0.01, respectively. Temporal demand was marginally significant, F (2,20) = 3.24, p<0.06. No other subscales were significant. To explain the main effect of configuration on the significant subscales, pairwise comparisons were conducted. Results showed that mental demand was significantly higher in ALTON than Fly-To or Point and Click configurations. Physical demand was significantly higher in the ALTON than the Fly-To or Point and Click configurations, p<0.02 and p<0.01, respectively. Temporal demand was significantly higher in the ALTON configuration than the Fly-To configuration, p<0.01. Frustration was significantly higher in the ALTON and Point and Click configurations than the Fly-To configuration, p<0.03 and p<0.01, respectively. Although performance was not statistically significant, the differences between configurations were practically significant. Perceived performance was highest in Fly-To than in all other configurations.

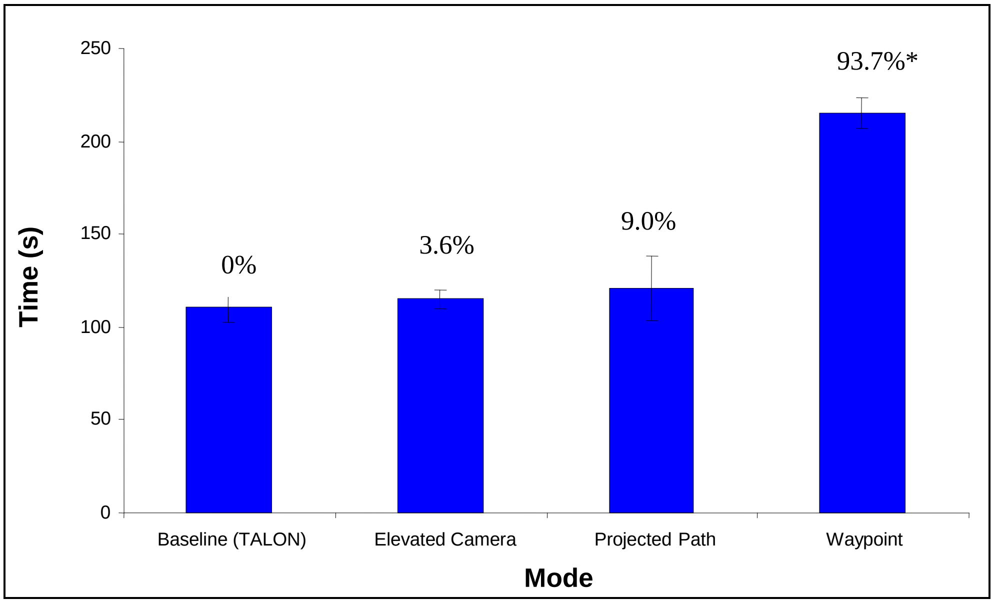
A second repeated measures ANOVA was conducted for overall workload. There was significant main effect of CARMAN configurations for overall workload, F (2,20) = 7.65, p <0.01. There was no difference in workload between trial 1 and trial 2 or an interaction of trial with configuration, F (1,10) = 2.63, p <0.13 and F (2,20) = 0.09, p = 0.91, respectively. To explain the main effect of configuration on overall workload, pairwise comparisons were conducted. Results showed that overall workload was significantly higher in the ALTON than the Fly-To or Point and Click configurations, p<0.01.

3.2 CATO Results

Repeated measures ANOVA and pairwise comparisons were used to analyze the performance differences of the four CATO configurations (Baseline (TALON)), Projected Path, Elevated Camera, and Waypoint)

Figure 14 presents the mean path following time (seconds) for the four CATO configurations. The percent change from Baseline (TALON) is listed over each bar. Significant differences (p's≤0.05) from Baseline are marked with an asterisk. For the path following course, Baseline was the quickest while Waypoint mode was the slowest.

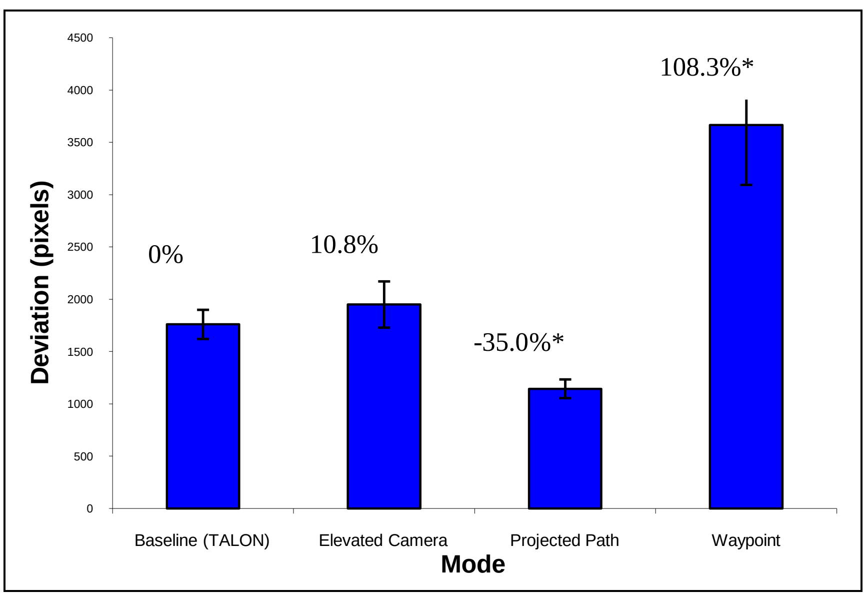
A mixed linear model analysis revealed a significant main effect of CATO configuration for path following time, F (3,33) = 24.02, p<0.01. There was a significant effect in path following time between trial 1 and trial 2, F (1,11) = 5.11, p<0.05, but there was no interaction of trial with configuration, F (3,33) = 0.99, p<0.40. To explain the main effect of configuration on path following time, pairwise comparisons were conducted. Results showed that significantly more time was needed to complete the path following portion for the Waypoint configuration than the other three configurations, p<0.01 for each. There were no significant differences between the other three modes.



Note: * = a significant difference.

Figure 14. Graph of mean (standard error of the mean) path following completion time for CATO configurations.

Figure 15 presents the mean path deviation (pixels) for the four CATO configurations. The percent change from Baseline (TALON) is listed over each bar. Significant differences (p<0.05) from Baseline are marked with an asterisk. Projected Path was the most precise at path following and Waypoint was the least precise.

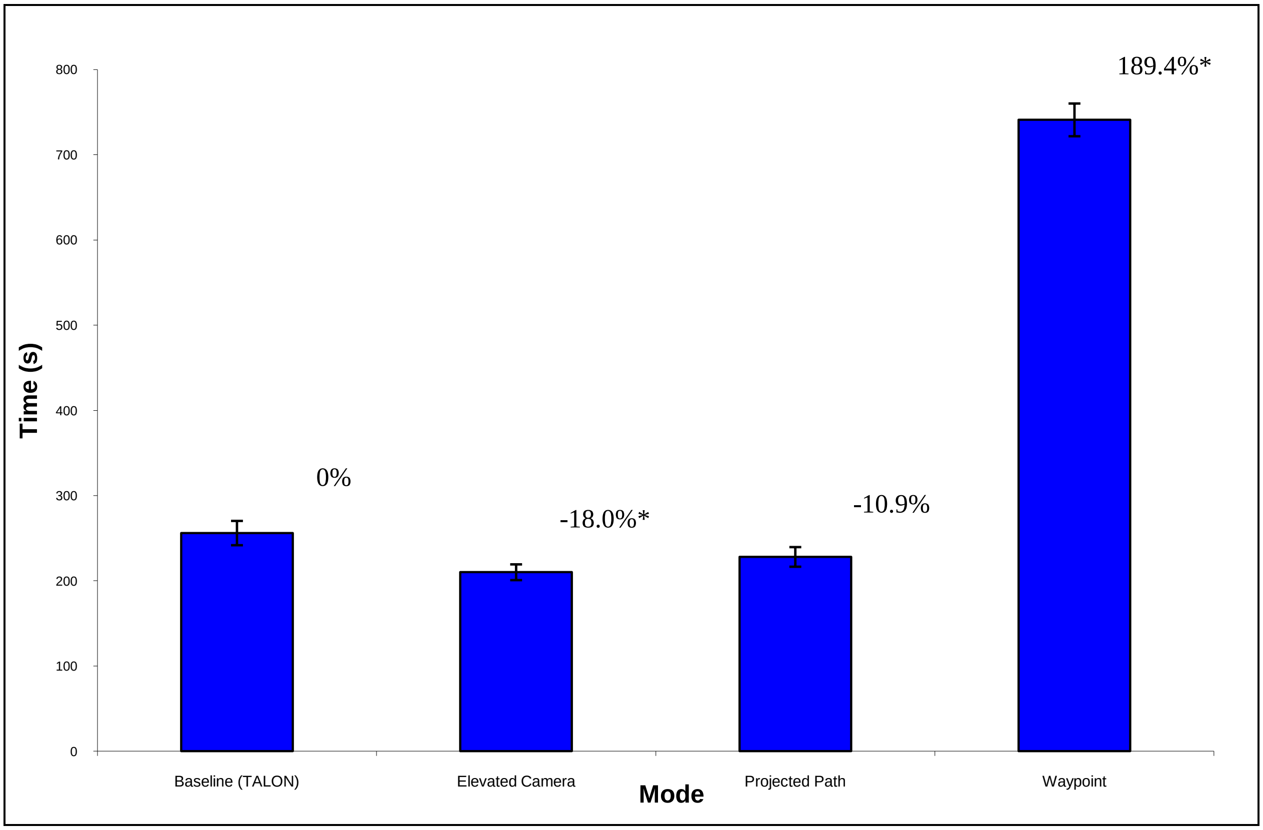


Note: * = a significant difference.

Figure 15. Graph of mean (standard error of the mean) path following deviation for CATO configurations.

A repeated measures ANOVA revealed a significant main effect of CATO configuration for path following deviation, $F\ (3,33) = 9.81$, $p<0.01$. There was no significant effect in path following deviation between trial 1 and trial 2 or an interaction of trial with configuration, $F\ (1,11) = 0.44$, $p<0.52$ and $F\ (3,33) = 1.28$, $p<0.29$, respectively. To explain the main effect of configuration on path following deviation, pairwise comparisons were conducted. Results showed that Projected Path configuration was significantly more precise than the other three configurations, p's<0.01. Results also showed that the Waypoint configuration was significantly less precise than the other three configurations, p's<0.03. There was no significant difference between the Baseline and Elevated Camera configuration.

Figure 16 presents the mean obstacle course completion time (seconds) for the four CATO configurations. The percent change from Baseline (TALON) is listed over each bar. Significant differences (p's<0.05) from Baseline are marked with an asterisk. Elevated Camera was the fastest mode for this course and Waypoint was the slowest.

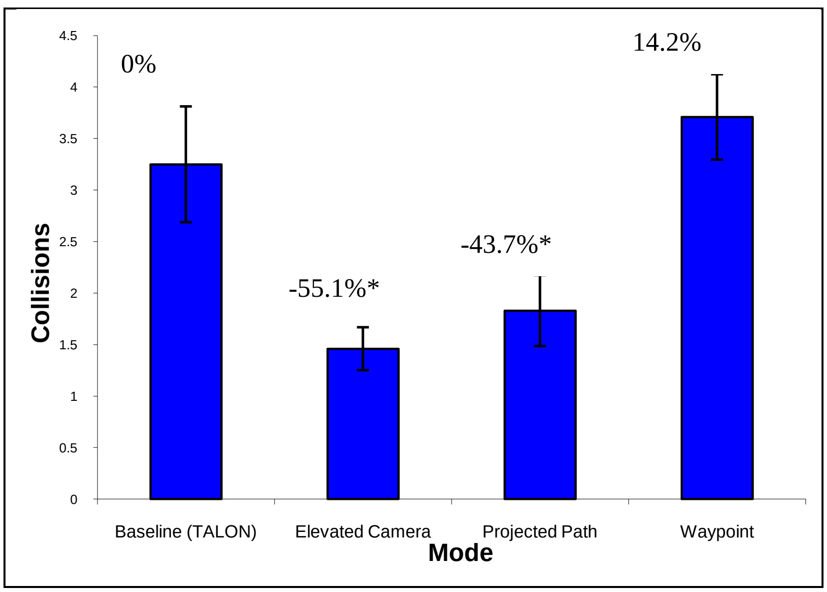


Note: * = a significant difference.

Figure 16. Graph of mean (standard error of the mean) obstacle course completion time for CATO configurations.

A repeated measures ANOVA revealed a significant main effect of CATO configuration for obstacle course time, F (3,33) = 52.15, $p<0.01$. There was no significant effect in obstacle course time between trial 1 and trial 2 or an interaction of trial with configuration, F (1,11) = 4.33, $p<0.062$ and F (3,33) = 0.95, $p<0.42$, respectively. To explain the main effect of configuration on obstacle course time, pairwise comparisons were conducted. Results showed that Elevated Camera configuration was significantly faster than the Baseline configuration, $p<0.02$. Results also showed that significantly more time was needed to complete the obstacle course for the Waypoint configuration than the other three configurations, p's<0.01. There were no significant differences between Projected Path and Elevated Camera or between Projected Path and Baseline for obstacle course completion time.

Figure 17 presents the mean number of obstacle collisions for the four CATO configurations. The percent change from Baseline (TALON) is listed over each bar. Significant differences (p's<0.05) from Baseline are marked with an asterisk. Elevated Camera resulted in the least number of collisions and Waypoint resulted in the most.



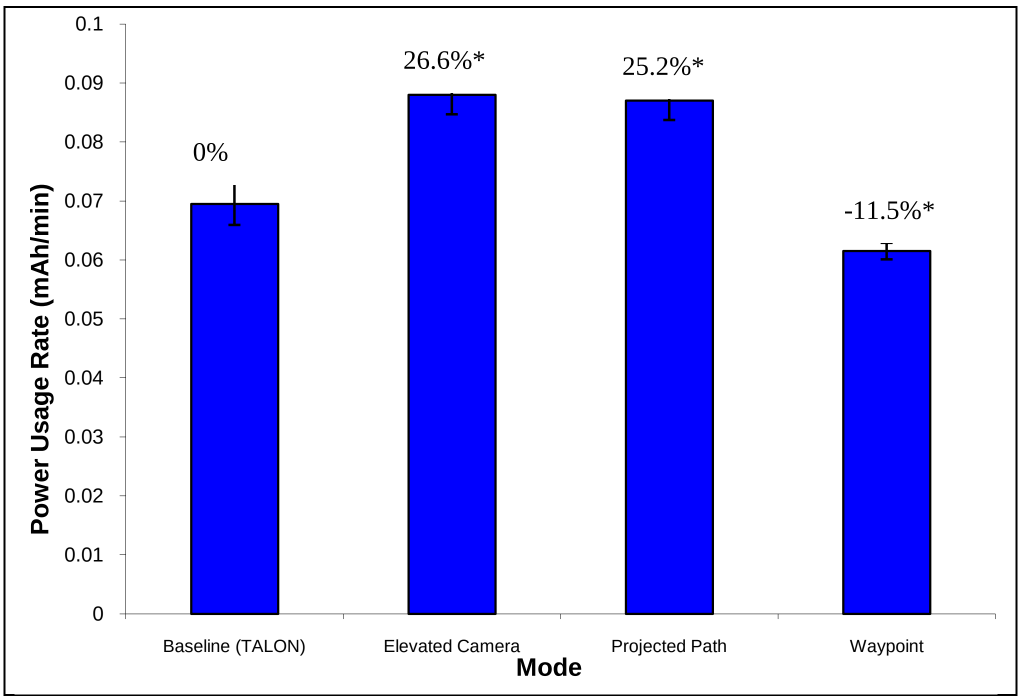
Note: * = a significant difference.

Figure 17. Graph of mean (standard error of the mean) obstacle collisions for CATO configurations.

A repeated measures ANOVA revealed a significant main effect of CATO configuration for obstacle collisions, F (3,33) = 8.07, $p<0.01$. There was no significant effect in collisions between trial 1 and trial 2 or an interaction of trial with configuration, F (1,11) = 1.96, $p<0.19$ and F (3,33) = 1.79, $p<0.42$, respectively. To explain the main effect of configuration on path following time, pairwise comparisons were conducted. Results showed that Elevated Camera and Projected Path configurations yielded significantly less collisions than the Baseline

configuration, $p<0.01$ and $p<0.05$, respectively. Results also showed that significantly more collisions resulted from the Waypoint configuration than the Elevated Camera or Projected Path configurations, p's<0.01. There was no significant difference between the Baseline and Waypoint modes or between Elevated Camera and Projected Path for number of collisions.

Figure 18 presents the mean power usage rate for the four CATO configurations. The percent change from Baseline (TALON) is listed over each bar. Significant differences (p's<0.05) from Baseline are marked with an asterisk. Despite taking longer to complete both the path following and obstacle sections of the course, Waypoint uses the least power per minute of operation. Elevated Camera was found to use the most power per minute of operation.



Note: * = a significant difference.

Figure 18. Graph of mean (standard error of the mean) power consumption rates for CATO configurations.

A repeated measures ANOVA revealed a significant main effect of CATO configuration for rate of power consumption, $F(3,33) = 16.32$, $p<0.01$. There was no significant effect in collisions between trial 1 and trial 2 or an interaction of trial with configuration, $F(1,11) = 3.33$, $p<0.09$ and $F(3,33) = 2.10$, $p<0.12$, respectively. To explain the main effect of configuration on path following time, pairwise comparisons were conducted. Results showed that the Waypoint configuration yielded significantly less rate of power consumption than the other three configurations, p's<0.03. Results also showed that significantly less power per minute was used

by the Baseline configuration than the Elevated Camera and Projected Path, $p<0.01$ and $p<0.02$, respectively. There was no significant difference between the Elevated Camera and Projected Path modes for the rate of power consumption.

Power Consumption is not correlated with any individual metric. However there are some interesting observations. First, although overall completion time is similar for Baseline, Elevated Camera, and Projected Path, the Baseline mode uses significantly less power. Second, while Elevated Camera and Projected Path modes perform better in terms of path precision and avoiding collisions than Baseline, the cost is higher power consumption.

A MANOVA was conducted to examine the effects of the four CATO configurations (Baseline-TALON, Elevated Camera, Projected Path, and Waypoint) on subjective workload. Subsequent ANOVAs and pairwise comparisons were conducted for the significant workload subscales.

Figure 19 presents a graph of mean workload across the CATO configurations. Results showed that subjective workloads were higher in the Waypoint and TALON configurations than the Elevated Camera and Projected Path for all six subscales. Table 4 lists the percent change in workload from Baseline for the three CATO modes.

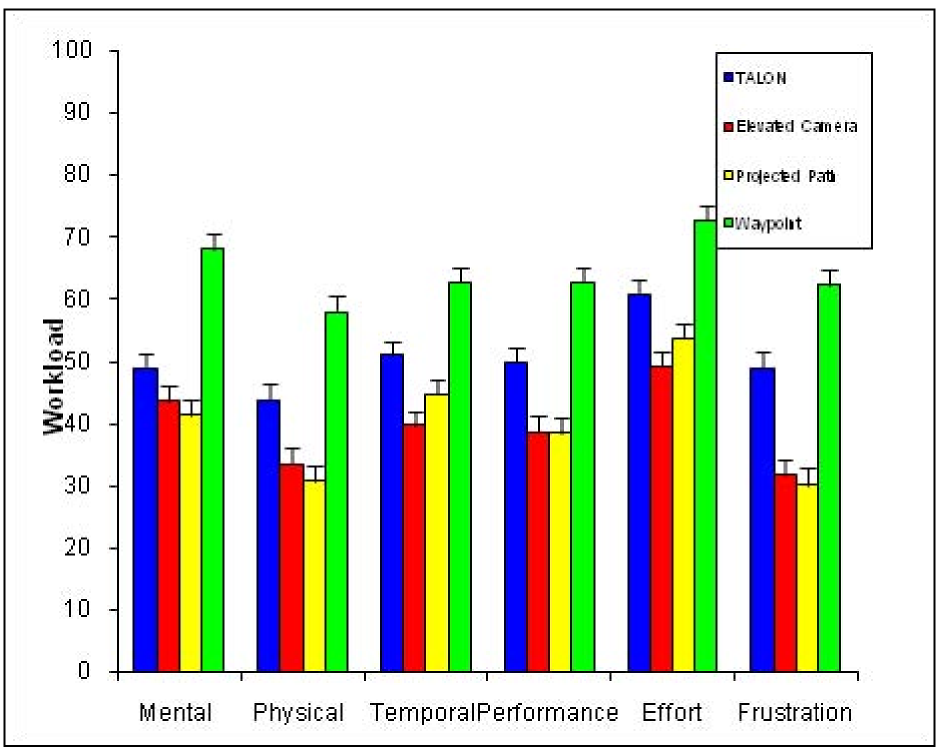


Figure 19. Graph of mean (standard error of the mean) subjective workload for CATO configurations.

Table 4. Table of percentages of workload from baseline (TALON) by configuration.

	Mental	**Physical**	**Temporal**	**Performance**	**Effort**	**Frustration**	**Overall**
Baseline (TALON)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Elevated Camera	–10.7%	–23.5%	–22.1%	–22.3%[a]	–18.9%	–35.2%[a]	–19.3%
Projected Path	–15.3%	–29.5%[a]	–12.2%	–22.6%	–11.6%	–38.3%[a]	–14.9%
Waypoint	39.1%[a]	32.4%	22.9%	25.9%	19.5%	27.2%	30%[a]

[a] Significant comparison between configuration and baseline (TALON), $p<0.05$.

A repeated measures MANOVA revealed a main effect of CATO configuration on workload, *Wilks* λ (21, 69) = 2.31, $p<0.01$. There was a significant difference in workload between trial 1 and trial 2, F (7,4) = 6.86, $p<0.041$. There was not an interaction of trial with configuration, F (21,69) = 1.06, $p<0.41$. Subsequent ANOVAs were conducted to determine which subscales of the NASA-TLX workload scale contributed to this main effect. There were significant main effects of CATO configuration for all six subscales—Mental: F (3,30) = 8.05, $p<0.01$; Physical: F (3,30) = 6.44, $p<0.01$; Temporal: F (3,30) = 4.47, $p<0.01$; Performance: F (3,30) = 7.76, $p<0.01$; Effort: F (3,30) = 5.65, $p<0.01$; Fatigue: F (3,30) = 10.38, $p<0.01$. To explain the main effect of configuration on the significant subscales, pairwise comparisons were conducted. Results showed that there were no significant differences between Elevated Camera and Projected Path for any of the subscale ratings. There were no significant differences between TALON and Waypoint, except for a significantly higher mental demand for Waypoint configuration, $p<0.02$. Waypoint yielded significantly higher workload than both Elevated Camera and Projected Path for all six subscales, p’s <0.01. TALON had significantly higher workload than Elevated Camera for performance and frustration, $p<0.05$ and $p<0.01$, respectively. TALON configuration had significantly higher workload than Projected Path for physical and frustration.

A second repeated measures ANOVA was conducted for overall workload. There was a significant main effect between CATO configurations for overall workload, F (3,30) = 9.86, $p<0.01$. To explain the main effect of configuration on the overall workload, pairwise comparisons were conducted. Waypoint had significantly greater overall workload than the other three configurations, p’s<0.01. There were no other significant differences between the configurations for total workload.

4. Conclusions

The objective of this research was to experimentally assess the value added of the CARMAN and CATO technologies to manipulation and tele-operation, respectively. To achieve this goal, ARL-Human Research and Engineering Directorate (HRED) in collaboration with AMRDEC developed an experiment plan. AMRDEC provided the hardware and software necessary to complete the experiment. ARL conducted the experiment and analyses described in this report.

4.1 CARMAN

For CARMAN, a light board was built. Targets that varied in size and location were projected on the board. Participants used the CARMAN technologies to move the manipulator arm to the target. The CARMAN technologies used were the Baseline configuration (ALTON), Fly-To, and Point and Click configuration. Results showed that performance with the Fly-To configuration was superior to the other two configurations. More specifically, fewer targets were missed in the Fly-To configuration than either the Baseline (ALTON) or the Point and Click configuration. Although Point and Click was developed to aid object manipulation, it did not improve performance relative to the Baseline (ALTON). Interestingly, task time was longer for Point and Click than Baseline, which was contrary to our prediction. In addition to objective performance, we assessed operator workload after each experimental trial. The subjective data complemented the objective results. In the Point and Click mode participants reported more time pressure, irritation, and stress during the task than in the Baseline configuration. The reason for these objective and subjective findings may be in the implementation of Point and Click configuration. In this mode the participant lined up the manipulator with the target and then the arm moved close to the location. The participant then had to switch to the basic mode and complete the manipulation task manually. In contrast, the Fly-To configuration did not require this last-minute manual adjustment by the operator. Thus, the Fly-To technologies successfully improved object manipulation, moving the manipulator arm to a target of interest. This technology improved the speed and accuracy with which the operator reached a target, with lower reported workload ratings.

4.2 CATO

For the CATO task an obstacle course was created outside. The course included a painted path to follow, gates, slaloms, and obstacles. Participants used the CATO technologies to maneuver through the course. The course was primarily divided into two portions; a path following section and an obstacle course section. The CATO technologies were the Baseline configuration (TALON IIIB), Elevated Camera, Projected Path, and Waypoint configuration. Across all tasks, Waypoint configuration was found to be the least suitable. This is not surprising since the

proposed application of Waypoint configuration is to allow the operator to move in a straight line at a constant speed while performing a visual search or other task. The CATO driving course was not designed to test that type of UGV mission. While the three remaining configurations allowed completion of the path-following section at similar speeds, the Projected Path configuration was superior in minimizing deviation from the path to be followed. This verified the primary purpose of the Projected Path configuration; to align the robot with a chosen path. It is interesting that the operators did not slow down when they were having difficulty following the path. The operators generally maintained a constant speed and did their best to apply a "closed-loop" course correction to the path as they progressed. While both Projected Path and Elevated Camera showed improvement from the Baseline configuration during the obstacle course segment, the Elevated Camera was best at both speed and accuracy in completing the obstacle course. The extra-wide field of view was instrumental in assisting the operator to pass though narrow openings (such as the slalom and gate obstacles) in a quick and efficient manner. The projected path configuration did allow the operators to align the robot with the opening, but the reduction in field of view was a detriment to performance in that configuration. In an informal survey, the participants reported an overwhelming preference for using Projected Path for the path following segment and a nearly even split for preferring Projected Path or Elevated Camera for the obstacle course. This preference was echoed in the decreased workload scores for Elevated Camera and Projected Path compared to Baseline or Waypoint configurations.

4.3 Summary

The objective of this research was to experimentally evaluate the effect of CARMAN and CATO technologies on manipulator activity and tele-operation, respectively. These technologies were assessed to gauge their effectiveness relative to standard operation of a TALON IIIB. CARMAN involves the development of technologies to reduce robotic manipulator task times and improve the precision of robotic manipulator placement. CATO involves the development of technologies to reduce tele-operated robotic mobility task times and improve the precision of tele-operated driving. The results of this technical test indicate that not only do CARMAN and CATO technologies increase accuracy and precision with respect to manipulator activity and tele-operation, but also significantly decrease mission times.

Appendix A. Informed Consent Form

This appendix appears in its original form without editorial change.

VOLUNTEER AGREEMENT AFFIDAVIT:

ARL-HRED Local Adaptation of DA Form 5303-R. For use of this form, see AR 70-25 or AR 40-38

The proponent for this research is:	**U.S. Army Research Laboratory Human Research and Engineering Directorate Aberdeen Proving Ground, MD 21005**

Authority:	Privacy Act of 1974, 10 U.S.C. 3013, [Subject to the authority, direction, and control of the Secretary of Defense and subject to the provisions of chapter 6 of this title, the Secretary of the Army is responsible for, and has the authority necessary to conduct, all affairs of the Department of the Army, including the following functions: (4) Equipping (including research and development), 44 USC 3101 [The head of each Federal agency shall make and preserve records containing adequate and proper documentation of the organization, functions, policies, decisions, procedures, and essential transactions of the agency and designed to furnish the information necessary to protect the legal and financial rights of the Government and of persons directly affected by the agency's activities]
Principal purpose:	To document voluntary participation in the Research program.
Routine Uses:	The SSN and home address will be used for identification and locating purposes. Information derived from the project will be used for documentation, adjudication of claims, and mandatory reporting of medical conditions as required by law. Information may be furnished to Federal, State, and local agencies.
Disclosure:	The furnishing of your SSN and home address is mandatory and necessary to provide identification and to contact you if future information indicates that your health may be adversely affected. Failure to provide the information may preclude your voluntary participation in this data collection.

Part A • Volunteer agreement affidavit for subjects in approved Department of Army research projects

Note: Volunteers are authorized medical care for any injury or disease that is the direct result of participating in this project (under the provisions of AR 40-38 and AR 70-25).

Title of Research Project:	Technical Testing of the CARMAN and CATO technologies	
Human Use Protocol Log # Number:	ARL-20098-08035	
Principal Investigator:	Regina Pomranky U.S. Army Research Laboratory Human Factors Integration Division Fort Rucker Field Element	Phone: 334-255-2135 E-Mail: rpomranky@arl.army.mil
Associate Investigator(s)	Keryl A. Cosenzo, Ph. D U.S. Army Research Laboratory Soldier Performance Division Crew Station Branch	Phone: 410-278-5885 E-Mail: kcosenzo@arl.army.mil
Associate Investigator(s)	Brad Pettijohn U.S. Army Research Laboratory Human Factors Integration Division Fort Leonard Wood Field Element	Phone: 573-563-5326 E-Mail: brad.pettijohn@us.army.mil
Associate Investigator(s)	Andrew Bodenhamer U.S. Army Research Laboratory Human Factors Integration Division Fort Leonard Wood Field Element	Phone: 573-563-6031 E-Mail: andrew.s.bodenhamer@us.army.mil
Location of Research:	ARMDEC Huntsville, AL	
Dates of Participation:	November 2008	

Part B • To be completed by the Principal Investigator
Note: Instruction for elements of the informed consent provided as detailed explanation in accordance with Appendix C, AR 40-38 or AR 70-25.

Purpose of the Research

The purpose of this research is to test the performance effects of the Computer Aided Tele-operation (CATO) and Computer Aided Robotic Manipulation (CARMAN) technologies. The CATO technology is a driving aids software. The CARMAN technology is a manipulator control software package. We are evaluating the new experimental driving aid and manipulator control software to assess the performance effects of operating ground vehicles by remote control with and without these new technologies.

Procedures

This experiment is divided into three experiments during the day. In Experiment I, you will control the TALONIIIB manipulator arm. The objective will be to manipulate the manipulator arm to hit 20 targets that will be displayed on a light board as quickly and accurately as possible. In Experiment II, you will remotely drive the TALONIIIB through an outdoor obstacle course. The objective will be to maneuver the unmanned system through the obstacle course as quickly and accurately as possible. In Experiment III, you will remotely drive a HMMWV through an outdoor obstacle course. The objective will be to maneuver the unmanned system through the obstacle course as quickly and accurately as possible. Experimental I will take place in an indoor climate-controlled laboratory. Experiment II will take place outdoors on a mowed field on which our obstacle course laid out. Experiment III will take place outdoors on an airfield airstrip.

You will complete Experiment I, II, and III in one eight hour day. A 30 minute break will be taken between each experiment and 45 minutes will be given for lunch. At the start of each experiment you will be given an overview of and training on the baseline and advanced configurations for the technology. You will then complete a training run. You will have the opportunity to repeat the training run until you are comfortable controlling the robot. Criteria for efficient training will be determined by a Subject Matter Expert on the platform who will be present during the training mission. These subject matter experts are the engineers of the CARMAN and CATO software and will use their knowledge of the system to assess training effectiveness. After training you will complete the experimental runs. At the end of each run you will complete the NASA-TLX to assess you workload during the task. Total participation time will be approximately eight hours.

Benefits

You will receive the personal satisfaction of providing valuable information to the Army's unmanned systems research.

Risks

The risks that will be encountered in this study are minimal and typical of the everyday risks encountered by military and civilian personnel performing office duties using their computers. Mild motion sickness may be experienced due to operation of an operator control unit to control an unmanned system. A motion sickness questionnaire will be used to assess this risk. A comparison of the pre- and post-experimental response patterns across the questionnaire will be conducted to evaluate motion sickness. If you show elevated scores on any of the items, you will be held at the research site until their symptoms abate.

Photography

Photographs and video may be recorded during the experiment. Photographic or video images of you taken during this data collection will not be identified with any of your personal information (name, rank, or status).

We would like your permission to take pictures/videotape/audio record during the experimental session. The pictures/recording may be used in reports or presentations of this work. Please indicate below if you will agree to allow us to record you. You can still be in the study if you prefer not to be recorded.

I give consent to be audio taped during this study: ____Yes ____No please initial:____

I give consent to be videotaped during this study: ____Yes ____No please initial:____

I give consent to be photographed during this study: ____Yes ____No please initial:____

Confidentiality

All data and information obtained about you will be considered privileged and held in confidence. All examinations will be recorded using a volunteer identifier code and a separate file with your consent form and the Principal Investigator will keep your assigned volunteer identifier code in a locked cabinet. Complete confidentiality cannot be promised, particularly if you are a military service member, because information bearing on your health may be required to be reported to appropriate medical or command authorities. In addition, applicable regulations note the possibility that the U.S. Army Human Research Protection Office officials may inspect the records. In order to ensure that your data will not be reported or revealed to anyone, each form will be reviewed upon receipt by one of the investigators. If any identifying information appears on the questionnaires (such as name, social security number, birth date, etc.), the investigators will delete the identifying information and replace it with a neutral code number. All investigators perusing the questionnaires and forms for any sensitive subject information put on the forms have taken Human Use Training.

Disposition of Volunteer Agreement Affidavit

The Principal Investigator will retain the original signed Volunteer Agreement Affidavit and forward a photocopy of it to the Chair of the Human Use Committee after the data collection. The Principal Investigator will provide a copy of the signed and initialed Affidavit to you.

Contacts for Additional Assistance

If you have questions concerning your rights on research-related injury, or if you have any complaints about your treatment while participating in this research, you can contact:

Chair, Human Use Committee **U.S. Army Research Laboratory** **Human Research and Engineering Directorate** **Aberdeen Proving Ground, MD 21005** **(410)278-5992**	**OR**	**Office of the Chief Counsel** **U.S. Army Research Laboratory** **2800 Powder Mill Road** **Adelphi, MD 20783-1197** **(301) 394-1070 or (DSN) 290-1070**

I do hereby volunteer to participate in the research project described in this document. I have full capacity to consent and have attained my 18th birthday. The implications of my voluntary participation, duration, and purpose of the research project, the methods and means by which it is to be conducted, and the inconveniences and hazards that may reasonably be expected have been explained to me. I have been given an opportunity to ask questions concerning this research project. Any such questions were answered to my full and complete satisfaction. Should any further questions arise concerning my rights or project related injury, I may contact the **ARL-HRED Human Use Committee Chairperson at Aberdeen Proving Ground, Maryland, USA by telephone at 410-278-5992 or DSN 298-5992.** I understand that any published data will not reveal my identity. If I choose not to participate, or later wish to withdraw from any portion of it, I may do so without penalty. I understand that military personnel are not subject to punishment under the Uniform Code of Military Justice for choosing not to take part as human volunteers and that no administrative sanctions can be given me for choosing not to participate. I may at any time during the course of the project revoke my consent and withdraw without penalty or loss of benefits. However, I may be required (military volunteer) or requested (civilian volunteer) to undergo certain examinations if, in the opinion of an attending physician, such examinations are necessary for my health and well-being.

Printed Name Of Volunteer (First, MI., Last)	
Social Security Number (SSN)	***Permanent Address Of Volunteer***
Date Of Birth (Month, Day, Year)	
Today's Date (Month, Day, Year)	***Signature Of Volunteer***

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Appendix B. Demographics Questionnaire

This appendix appears in its original form without editorial change.

Participant ID# __________

Demographic and Computer Experience Questionnaire

1. AGE: _____

2. GENDER: ___Male ___ Female

3. Do you wear glasses? ___ Yes ___ No

4. Do you have any reason to believe that you have a hearing impairment? ___Yes ___ No

5. Please indicate your highest level of education:
   ___ High School Diploma
   ___ Undergraduate Degree
   ___ Some graduate courses
   ___ Graduate Degree
   ___ Other

6. Are you or have you been in the military? ___Yes ___No If yes, what Branch? _________________

   For how many years? ___Less than 5 years ___5-10 years ___ 11-15 years ___16-20 years ___ 20 years or more

7. Does your job require you to use a computer on a regular basis? ___Yes ___No

8. How long have you been using a computer?

__Less than 1 year ___ 1-3 years ___4-6 years ___7-10 years ___10 years or more

9. How often do you use a computer?

___Daily ___Weekly ___Monthly ___Once or twice a year

10. Do you have a computer in your house? ___Yes ___No

11. Do you use the computer to play games? ___Yes ___No

   If yes, how often? ___Daily ___Weekly ___Monthly ___Once or twice a year

12. What is your level of experience with the operation of unmanned systems?

No previous experience _____
Some experience (1-3 times) _____
Substantial experience (More than 3 times)________

If you have experience, with what systems do you have experience?

For what application(s) did you use unmanned systems?

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Appendix C. NASA TLX Questionnaire

This appendix appears in its original form without editorial change.

NASA TLX Questionnaire

Participant ID:________________

TLX Workload Scale

Please rate your workload by putting a mark on each of the six scales at the point which matches your experience.

Mental Demand

Low **High**

Physical Demand

Low **High**

Temporal Demand

Low **High**

Performance

Good **Poor**

Effort

Low **High**

Frustration

Low **High**

Appendix D. Symptom Questionnaire

This appendix appears in its original form without editorial change.

Symptom Questionnaire Participant ID: ________________

Condition:____________ Date: _____________________ Time: __________________

Using the scale below, please rate how accurately the following statements describe your experience.

1. I feel sick to my stomach	Not at all Severely 1-------2-------3-------4-------5-------6-------7-------8-------9
2. I feel faint-like	Not at all Severely 1-------2-------3-------4-------5-------6-------7-------8-------9
3. I feel annoyed / irritated	Not at all Severely 1-------2-------3-------4-------5-------6-------7-------8-------9
4. I feel sweaty	Not at all Severely 1-------2-------3-------4-------5-------6-------7-------8-------9
5. I feel queasy	Not at all Severely 1-------2-------3-------4-------5-------6-------7-------8-------9
6. I feel lightheaded	Not at all Severely 1-------2-------3-------4-------5-------6-------7-------8-------9
7. I feel drowsy	Not at all Severely 1-------2-------3-------4-------5-------6-------7-------8-------9
8. I feel clammy / cold sweat	Not at all Severely 1-------2-------3-------4-------5-------6-------7-------8-------9
9. I feel disoriented	Not at all Severely 1-------2-------3-------4-------5-------6-------7-------8-------9
10. I feel tired / fatigued	Not at all Severely 1-------2-------3-------4-------5-------6-------7-------8-------9
11. I feel nauseated	Not at all Severely 1-------2-------3-------4-------5-------6-------7-------8-------9
12. I feel hot / warm	Not at all Severely 1-------2-------3-------4-------5-------6-------7-------8-------9
13. I feel dizzy	Not at all Severely 1-------2-------3-------4-------5-------6-------7-------8-------9
14. I feel like I was spinning	Not at all Severely 1-------2-------3-------4-------5-------6-------7-------8-------9
15. I feel as if I may vomit	Not at all Severely 1-------2-------3-------4-------5-------6-------7-------8-------9
16. I feel uneasy	Not at all Severely 1-------2-------3-------4-------5-------6-------7-------8-------9

List of Symbols, Abbreviations, and Acronyms

3-D	three-dimensional
AMRDEC	Aviation and Missile Research, Development and Engineering Center
ARL	U.S. Army Research Laboratory
BAT	Battlefield Automation Team
CARMAN	Computer Aided Robotic Manipulation
CATO	Computer Aided Tele-operation
EOD	explosive ordnance disposal
HRED	Human Research and Engineering Directorate
IED	improvised explosive device
MTBF	mean time between failures
MTTR	mean time to repair
NASA-TLX	NASA-Task Load Index
OCU	Operator Control Units
SED	Software Engineering Directorate
SUGV	small unmanned ground vehicle
UAV	unmanned aerial vehicle
UGV	unmanned ground vehicle

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